The Solar Orbiter Science Activity Plan: translating solar and heliospheric physics questions into action

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The Solar Orbiter Science Activity Plan

Translating solar physics questions into action

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ABSTRACT

Solar Orbiter is a space mission, launched in February 2020, with its main goal to observe solar activity from close by, both in and out of the ecliptic, and to link it to the solar plasma as sensed by its in-situ sensors. The payload consists of 6 remote-sensing and 4 in-situ instrument suites, which will have to coordinate their operations to address the four mission objectives:
(1) What drives the solar wind and where does the coronal magnetic field originate?
(2) How do solar transients drive heliospheric variability?
(3) How do solar eruptions produce energetic particle radiation that fills the heliosphere?
(4) How does the solar dynamo work and drive connections between the Sun and the heliosphere?
To maximise the mission's science return, it needs to be considered that each orbit around the Sun has different characteristics, including the relative position of the spacecraft to Earth (affecting downlink rates), trajectory events (such as gravitational assist manoeuvres), and the phase of the solar activity cycle. Furthermore, each orbit's science telemetry will be downloaded over the course of the following orbit, so science operations must be planned at mission level, rather than at the level of individual orbits. So how will those science questions be translated into an actual plan of observations that will fit into the mission and make sure that no opportunities are missed? First, the high-level objectives are broken down into specific, answerable questions along with the observations they need from the payload. In order to achieve this, the so-called Science Activity Plan (SAP) has been developed. The SAP groups together objectives that require similar observations into Solar Orbiter Observing Plans (SOOPs), resulting in a strategic, top-level view of the optimal opportunities for science observations across the mission lifetime, allowing all four mission objectives to be addressed. In this paper, we introduce Solar Orbiter's SAP through a series of examples and the strategy being followed.

Key words. Sun: general – Sun: magnetic fields – Sun: activity – Sun: atmosphere – Sun: solar wind – Methods: observational

1. Introduction

Coordination and planning will be the key to the scientific success of Solar Orbiter, the new solar physics mission of the European Space Agency (ESA) jointly developed with NASA and launched in February 2020 (Müller et al. 2020). This need for planning originates from the science objectives of the mission, the capabilities of the platform and the payload, and has driven the design of the operations concept. Observations will need to be coordinated between the remote-sensing and in-situ payload, amongst the remote-sensing instruments themselves (Auchere et al. 2020) and also amongst the in-situ instruments (Walsh et al. 2020). The science return of Solar Orbiter and other contemporary space missions, particularly Parker Solar Probe (Fox et al. 2016) and Bepi Colombo (Benkhoff et al. 2010), and ground-based facilities like the Daniel K. Inouye Solar Telescope (see Tritschler et al. 2016, for example) will also be enhanced through cross-facility coordination, as far as is possible within the constraints under which each facility operates.

The Science Activity Plan (SAP) has been built over the last few years with the contribution of a significant part of the international solar physics and heliophysics community. It describes in a structured way all scientific activities to be carried out by the instruments throughout all science mission phases to fulfil the science requirements of the mission. It tracks how high-level science objectives are mapped to more specific scientific objectives and these, in turn, to scientific activities that will be scheduled at specific times during the mission. As context information, it also contains instrument operations scenarios and modelling, and a description of all mission phases. One of the main reasons for mission level planning is to make sure that we will have enough opportunities to address all mission's science objectives in an optimal way. More importantly, we need to make sure that if e.g., a unique opportunity exists for a specific science goal at a given date or configuration, this goal should be given priority. From this point of view, priorities have to be given not only based on the importance of the science objective (which is sometimes difficult to judge depending on the interests of the science community that cannot be anticipated with many years in advance), but also on many other circumstances that are detailed in this paper.

In the following sections we explain the observing campaigns – called SOOPs for 'Solar Orbiter Observing Plans' –, which are the building blocks of the SAP, and the strategy that we will adopt in building the plan during the next decade within the Science Working Team. The paper's purpose is to provide the scientific community with a reference guide regarding the different SOOPs, especially to those scientists that are not directly involved in the elaboration of the science plan, but will be the ultimate users of the observations.

2. Solar Orbiter Science Objectives

Solar Orbiter's objective is to address the central question of heliophysics: how does the Sun create and control the heliosphere? This, in turn, is a fundamental part of the second science question of ESA's Cosmic Vision programme: 'How does the solar system work?'. Solar Orbiter is specifically designed to identify the origins and causes of the solar wind, the heliospheric magnetic field, solar energetic particles, transient interplanetary disturbances, and the Sun's magnetic field itself.

The supersonic solar wind, driven by dynamic plasma and magnetic processes at the Sun's surface, expands to surround the solar system's planets and the space far beyond. Below the surface, the solar dynamo drives magnetic fields whose buoyancy brings them to the surface where they form huge arcades of loops, which contain enormous amounts of stored energy. These magnetic loops are stretched and sheared by the Sun's differential rotation and partially unknown surface processes, eventually erupting in explosions, which eject magnetic structures that fly into the solar system, occasionally impacting Earth and its magnetic shield with disruptive effects on space and terrestrial systems. Understanding the complex physical processes at work in this system is the central goal of heliophysics. Since the Sun and presumably the heliosphere are typical of many small stars and their stellar spheres, these studies are relevant to astrophysics, but are unique since the Sun alone is close enough for detailed study.

Over the past 30 years, an international effort to understand the Sun and heliosphere has been undertaken with an array of spacecraft carrying out both remote observations at visible, UV, and X-ray wavelengths, as well as in-situ observations of interplanetary plasmas, particles, and fields. Combined and coordinated observations from missions such as Ulysses (Wenzel et al. 1992), Yohkoh (Acton et al. 1992), SOHO (Domingo et al. 1995), TRACE (Strong et al. 1994), RHESSI (Lin et al. 2002), Hinode (Kosugi et al. 2007), SDO (Pesnell et al. 2012) and STEREO (Kaiser et al. 2008) have resulted in an enormous advance in our understanding of the Sun and heliosphere, and have proven that critical progress in understanding the physics requires both remote and in-situ observations working together.

Although Earth's vantage point at 1 AU is close by astrophysical measures, it has long been known that much of the crucial physics in the formation and activity of the heliosphere takes place much closer to the Sun, and that by the time magnetic structures, shocks, energetic particles and solar wind pass by Earth they have already evolved and in many cases mixed so as to blur the signatures of their origin. With the proven effectiveness of combined remote and in-situ studies on the missions cited above, it is expected that critical new advances will be achieved by Solar Orbiter that combines remote and in-situ observations and gets closer to the Sun. From this inner-heliospheric vantage point, solar sources can be identified and studied accurately and combined with in-situ observations of solar wind, shocks, energetic particles, etc., before they evolve significantly.

This big challenging question has been expressed in the form of the following 4 science objectives (Müller et al. 2020):

(1) What drives the solar wind and where does the coronal magnetic field originate?

(2) How do solar transients drive heliospheric variability?

(3) How do solar eruptions produce energetic particle radiation that fills the heliosphere?

(4) How does the solar dynamo work and drive connections between the Sun and the heliosphere?

The Solar Orbiter science community has extensively detailed these objectives to better define what is needed to be observed. Around 500 sub-objectives have been defined that cover all the above questions. These are described in detail in the Science Activity Plan pages of the Solar Orbiter science website[1] and will be continuously updated as new knowledge becomes available.

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[1] https://www.cosmos.esa.int/web/solar-orbiter

3. Solar Orbiter Mission Planning Overview

The Solar Orbiter mission is unique from the operations point of view (see Sanchez et al. 2020), in the sense that this will be the first solar mission that carries Sun-observing telescopes that will get significantly closer to the Sun and explore all distances between 0.28 AU and 1 AU. In that sense the operations concept is very different from those of previous missions like SOHO, STEREO, Hinode, or SDO. As for all encounter and interplanetary missions, the various spacecraft resources are limited, a complexity that has to be taken into account in the operations philosophy. While the general mission planning approach for all routine science operations of Solar Orbiter was built on the experience of ESA's precursor solar system missions Mars Express, Venus Express, and Rosetta, a fundamental difference with respect to planetary missions is the highly dynamic nature of the Sun. In addition, while the in-situ instruments will operate continuously, this is not true for the remote-sensing instruments. During each orbit, the complete instrument suite (together with the remote-sensing instruments) will be operated during three 10-day windows, centred around closest approach, and at the minimum and maximum heliographic latitudes. These windows are called Remote-Sensing Windows (RSWs) and are in the heart of the science planning as explained in this paper. The resulting requirements on the science operations planning for remote-sensing observations are summarised below together with the mission planning cycle. Given the short time scales on which the targets of remote-sensing observations (e.g. solar active regions) change, together with the narrow fields of view of the high-resolution imaging telescopes (which cover less than 3% of the solar disk at perihelion), turn-around times between defining the pointing and executing the observations of at most three days are required during the Remote-Sensing Windows (RSWs).

3.1. Mission Planning Cycle

For each mission phase (Cruise Phase (CP), Nominal Mission Phase (NMP), Extended Mission Phase (EMP)), a baseline science plan is established and documented in the SAP before each mission phase commences. This plan takes into account the general characteristics and major constraints of each orbit. The SAP is a living document in the sense that it will be frequently updated as more and more science activities get worked out in detail, feedback from earlier observations (and their planning) is injected into the planning of later orbits, etc. It is important to stress that top-level science operations planning for the mission needs to be done well in advance due to the continuously changing orbital configuration, and to the fundamental constraints on Solar Orbiter's data downlink volume and onboard storage in the Solid State Mass Memory (SSMM). In fact, because of its unique orbit in the inner heliosphere, Solar Orbiter is a fundamentally different mission compared to typical solar missions like SOHO or SDO that are near-Earth or the STEREO spacecraft that are at 1 AU. It should rather be compared to a planetary or deep-space mission, which entails various operational constraints. Because of the varying distance r between Earth and the spacecraft, which can be up to 2 AU (when the spacecraft is at 1 AU from the Sun, but at the far side from Earth), the telemetry will be highly variable, reducing by $1/r^2$. Combined with a limited onboard data storage, this means that there will be times during the orbit when the SSMM will be full and any new observations would either be lost or overwrite older data. For preventing this, it is important to plan the observations accordingly, which is the objective of the SAP, but also to implement alternative solutions like selective data downlink, onboard data processing and compression whenever possible. We refer the reader to the individual instrument papers (this issue) for details on these functionalities that are implemented for some of the instruments to variable extents. Concerning the planning at mission level, the above constraints entail feasibility studies of planned operations taking into account the expected time-dependent telemetry downlink profile as well as SSMM load levels. The mission planning cycle for the routine science operations phase is therefore divided into the following different levels:

3.1.1. Long-Term Planning (LTP)

Long-Term Planning covers six-month periods starting in January or July; this is driven by the schedule of ground station allocations. It is the means by which the 10 instruments build a feasible, coordinated plan that will address the science objectives decided for that six month period in the SAP. In the early part of the mission, six months approximately correspond to an orbit, however later on, orbits will be shorter, so this correspondence will not always hold.

3.1.2. Short-Term Planning (STP)

Short-Term Planning will generate detailed schedules of commands for the spacecraft and for the ground stations. This process will take place typically every week covering one week. At STP level, the instrument activities can be modified, provided they fit into the resource envelope defined at LTP level.

3.1.3. Very-Short-Term Planning (VSTP)

In the case of RSWs, VSTP may be required to add flexibility in the pointing of the spacecraft and of all remote-sensing instruments. At this phase, even if all commands have been stored onboard of the spacecraft, we need to keep flexibility to respond to the dynamic nature of solar activity and to point the small, high-resolution cameras at the locations of the Sun with the highest science priority for that time. This planning level, with turn-around times of at most three days between observations and execution of the new Pointing Request (PTR), is required for RSWs in which features on the solar disk, e.g. active regions, shall be tracked over time. This is due to the short lifetimes and non-deterministic motion of targets on the Sun, and the absolute pointing error (APE) of the spacecraft, which depends on the spacecraft's temperature and can be relatively large compared to the fields-of-view of the high-resolution imaging telescopes. This VSTP consists of (i) initial target selection and (ii) updates to the pointing.

Prior to the start of a RSW, a limited set of precursor observations with the full-disk imaging telescopes of the EUI, PHI and Metis instruments is performed and downlinked with high priority. Based on the returned data, the target for the start of the RSW will be defined. This step is required to make a decision on the pointing of the spacecraft and, in turn, the high-resolution imaging telescopes. In case the orbital constellation permits making this decision by means of other observations (e.g. using ground-based telescopes), this step can be omitted.

During the course of a RSW, a limited set of daily low-latency data, consisting of full-disk and high-resolution images, will be downlinked with high priority. Based on the evaluation of these images, the pointing may be updated by means of uploading a PTR.

4. Solar Orbiter Observing Plans (SOOPs)

A SOOP (Solar Orbiter Observing Plan) is the analogue of a SOHO JOP and Hinode HOP.

SOHO Joint Observing Programmes (JOPs) were born of the need to occasionally coordinate the various, independently planned instruments, to create combinations of measurements that were indispensable for addressing certain science questions. This need for campaigns arose partly because of the fact that many instruments could point independently of the spacecraft and thus each other, and indeed operated independently. Nevertheless it was realised before the mission was launched that JOPs would be powerful tools for maximising the mission's science return. JOPs grew to often include resources beyond the mission itself, such as other satellites and ground-based facilities, and over 200 such campaigns came to be executed.

Hinode's mission concept is much more tightly coordinated in pointing than SOHO, because all fields-of-view are copointed. Its analogue of the JOP, the Hinode Operation Plan (HOP) has therefore typically been used in one of three ways: to establish importance of observations to the mission, by scheduling it usually months in advance; to ensure the coordination of the three instruments in time (and, in the case of its full-disk X-ray telescope, to use the correct sub-field of the FoV); and, most commonly, to coordinate with external facilities. Indeed, external coordination has been performed since the very first HOP.

Many JOPs and HOPs have been reused multiple times by their respective missions, since the rules of communication and coordination become more familiar once they have been established in the first attempts.

By analogy to JOPs and HOPs, the Solar Orbiter SOOP is a set of common operations from multiple instruments, that is, a collection of instrument modes and parameters designed to address a specific science goal, and it can be reused during different orbital opportunities. However, a specific SOOP can also be used to address other science goals than the one for which it has been primarily designed. For instance, a SOOP designed to study the dynamics of an active region with two different imagers at high spatial resolution and high temporal cadence can be used for sub-objectives as varied as: the study of the structure of a coronal mass ejection; understanding the energy release during a flare and the particle acceleration related to a magnetic reconnection process; or understanding how the magnetic fields emerge on the solar surface. This definition enables us to narrow down the different possibilities of SOOPs to 34 that will be used to address more than 500 sub-objectives, which makes the science operations for the whole mission simpler and more effective. Most of the SOOPs involve a large number of instruments, since coordinated campaigns are needed for most of the objectives. However, not every instrument is necessarily required in each SOOP: some instruments can make individual observations when they are not needed for the coordinated campaigns; likewise, multiple SOOPs can be executed in parallel if technically possible.

In this section we describe all the SOOPs that have been defined until now. We note that this is not a definitive list, since more possibilities may appear during the mission to reflect our enhanced understanding of the instruments' performance and the obtained data as well as the evolution of the scientific knowledge related to the different objectives. An up-to-date list together with detailed descriptions will always be available on the Solar Orbiter science website. For the names of the SOOPs we use the following format: $A\_B\_res\_cad\_description$. A can take the values I for in-situ only observations, i.e. only the in-situ instruments participate in this SOOP, R for remote-sensing only observations, and L for SOOPs that are designed for linking both in-situ and remote-sensing observations. B can take the values $FULL$ for imaging of the entire solar disk, $SMALL$ for a small field of view (e.g. for imaging a specific active region) and $BOTH$ when the above are combined. res refers to the spatial resolution of the imagers and it can take the values $LRES$, $MRES$ and $HRES$ for low, medium and high spatial resolution respectively. Same for cad but for the temporal cadence which can take the values $LCAD$, $MCAD$ and $HCAD$ for low, medium and high temporal cadence respectively. Lastly, a $description$ is added with a plain language word (e.g. coronal-dynamics, fast-wind etc.) to cover the main intent of the observations, as loosely as possibly so that it does not exclude any of the intended sub-objectives. The name is indicative of the observations, but in reality may not be the exact target that is observed. There are two SOOP names that do not follow the above rules (L_IS_STIX and $L\_IS\_SoloHI\_STIX$), but these SOOPs simply describe coordinated synoptic observations with the instruments named in the SOOP names (IS stands for in-situ in this particular case). The different names of SOOPs, defined as of today, can be found in Table 4 and are detailed in the following sections. For details about the instruments and their operational modes, see the individual instrument papers in this issue. For details about each SOOP and how it is going to address the particular sub-objectives, see the SAP pages of the Solar Orbiter science website.

Lastly, these SOOP names play a key role in identifying the resulting cohesive scientific datasets to the user in the Solar Orbiter ARchive (SOAR). Once they have already been downlinked processed and checked for calibration, all datasets from a given SOOP, from all participating instruments, will be linked and discoverable by searching for that SOOP name in the SOAR.

4.1. The in-situ baseline SOOP I_DEFAULT

I_DEFAULT is the baseline in-situ SOOP involving all 4 in-situ instruments EPD (Energetic Particle Detector, see Rodríguez-Pacheco et al. 2020), MAG (Magnetometer, see Horbury et al. 2020), RPW (Radio and Plasma Waves instrument, see Maksimovic et al. 2020) and SWA (Solar Wind Analyser, see Owen et al. 2020). This will be the standard SOOP that will run during the whole cruise phase and during the nominal phase outside the remote-sensing windows. It will also run in combination with other SOOPs during the remote-sensing windows. It is designed to address all in-situ objectives for which no remote-sensing observations are needed. The four instruments can be in normal or in burst mode, together or individually. For details regarding the coordinated campaigns of in-situ instruments, see Walsh et al. (2020). This SOOP covers all three top-level objectives regarding the solar wind, interplanetary magnetic fields, coronal mass ejections and energetic particles. For many of those, it is important to perform long-term observations with a good spatial and latitudinal coverage of the inner heliosphere during the different phases of the solar cycle. This is why the in-situ instruments will always be operating throughout the mission, within the operational constraints explained in Sanchez et al. (2020). Special care has been taken for Electro-Magnetic Cleanliness (EMC) and it is guaranteed that the spacecraft will be EMC-quiet during at least 70% of the time of the mission in order to acquire meaningful in-situ data (see Sanchez et al. 2020 and Garcia-Marirrodriga & Pacros 2020). Different objectives will have to take into account the best orbital opportunities. For instance, there are optimal geometrical configurations (e.g., radial alignments, align-

Table 1. List of Solar Orbiter Observing Plans (SOOPs)

SOOP names
I_DEFAULT
L_IS_STIX
L_IS_SoloHI_STIX
L_FULL_LRES_MCAD_Coronal-Synoptic
L_FULL_LRES_MCAD_Probe-Quadrature
L_FULL_MRES_MCAD_CME-SEPs
L_FULL_HRES_LCAD_MagnFieldConfig
L_FULL_HRES_MCAD_Coronal-He-Abundance
L_FULL_HRES_HCAD_Eruption-Watch
L_FULL_HRES_HCAD_Coronal-Dynamics
L_SMALL_MRES_MCAD_Ballistic-Connection
L_SMALL_MRES_MCAD_Connection-Mosaic
L_SMALL_HRES_HCAD_Fast-Wind
L_SMALL_HRES_HCAD_Slow-Wind-Connection
L_BOTH_MRES_MCAD_Farside-Connection
L_BOTH_LRES_MCAD_Pole-to-Pole
L_BOTH_MRES_MCAD_Flare-SEPs
L_BOTH_HRES_LCAD_CH-Boundary-Expansion
L_BOTH_HRES_HCAD_Major-Flare
R_FULL_LRES_LCAD_Transition-Corona
R_FULL_LRES_HCAD_Global-Helioseismology
R_FULL_HRES_HCAD_Density-Fluctuations
R_SMALL_MRES_MCAD_AR-Long-Term
R_SMALL_HRES_LCAD_Composition-vs-Height
R_SMALL_HRES_LCAD_Fine-Scale-Structure
R_SMALL_HRES_MCAD_Polar-Observations
R_SMALL_HRES_HCAD_Photospheric-Dynamics-Structure
R_SMALL_HRES_HCAD_AR-Dynamics
R_SMALL_HRES_HCAD_PDF-Mosaic
R_SMALL_HRES_HCAD_RS-Burst
R_SMALL_HRES_HCAD_Wave-Stereoscopy
R_SMALL_HRES_HCAD_Ephemeral
R_BOTH_HRES_HCAD_Nanoflares
R_BOTH_HRES_HCAD_Filaments

ments along the Parker spiral, and quadratures) between Solar Orbiter, Parker Solar Probe, BepiColombo, the Sun and Earth for which it will be particularly interesting to schedule burst modes (for the collaboration with other space and Earth assets see Velli et al. 2020). Whenever additional assets are used to improve our understanding of the various sub-objectives, these have been indicated in the SAP. In the following SOOPs, the in-situ instruments are always on, at least in normal mode, and we will not explicitly refer to them if not needed.

4.2. L_IS_STIX: the in-situ default SOOP enhanced with X-ray observations

For some objectives related to solar energetic particles (e.g., how they can be accelerated to high energies so rapidly, seed particles provided by flares, accelerate electrons on short timescales to explain hard X-ray fluxes, etc.), it is important to have information about X-ray emission in addition to the EPD measurements. This can be achieved by coupling the previous I_DEFAULT SOOP to the normal mode of the STIX instrument (Krucker et al. 2020). As per current plan, STIX is baselined to operate only during the remote-sensing windows, but executing this SOOP for longer periods, including outside the windows, would allow better statistics over the course of the solar cycle and across a range of heliospheric distances.

4.3. L_IS_SoloHI_STIX: the L_IS_STIX SOOP enhanced with spatial context from SoloHI

This SOOP aims to measure variability in gradual solar energetic particles events through the corona and the heliosphere. It is based on the previous L_IS_STIX SOOP, enhanced with spatial context from the heliospheric imager, SoloHI (Howard et al. 2020). This is for instance important when we want to study warped shock fronts, turbulence and inhomogeneities in general, probing solar wind turbulence, etc. The SoloHI Shock, Turbulence or Synoptic modes can be used (see Howard et al. (2020) for details) depending on the distance from the Sun (shock and turbulence modes are scheduled when the spacecraft is inside 0.4 AU). Some of the objectives require in-situ burst modes, whereas others would greatly benefit from the coordination with Parker Solar Probe.

4.4. Coronal Synoptic SOOP L_FULL_LRES_MCAD_Coronal-Synoptic

The coronal synoptic SOOP L_FULL_LRES_MCAD_Coronal-Synoptic is designed to provide insight into the global coronal structure and study coronal mass ejections. When scheduled, it typically runs for a whole remote-sensing window (default duration of 10 days). The imagers would point to disk centre (no off-pointing to a different region of the Sun is needed), and the SOOP can make use of the in-situ and Metis instrument triggers. It is important to note that many instruments have triggers in their onboard systems. The EUI has a flare trigger responding to intensity enhancements in EUI/FSI (Full Sun Imager)); STIX has a flare trigger responding to flares in the X-ray; and Metis has a CME trigger that responds to enhancements in white light emission off-limb. The EPD instrument triggers to burst mode when the energetic particle fluxes in different energy ranges reach certain thresholds. RPW triggers to burst mode when it detects interplanetary shocks or type III bursts. The whole payload participates in this SOOP except SPICE (SPICE Consortium et al. 2020), which has only a narrow field-of-view. The Extreme Ultraviolet Imager (EUI, see Rochus et al. 2020) makes use of the Full Sun Imager (FSI) at its synoptic mode with a cadence around 10 minutes (all SOOPs' cadences may be adjusted when scheduling them). The Metis coronagraph (Antonucci et al. 2020) uses the GLOBAL mode and the CMEOBS special mode whenever triggered. The Photospheric and Helioseismic Imager (PHI, see Solanki et al. 2020) is observing with the Full Disk Telescope (FDT) synoptic mode with a cadence of 6 hours. SoloHI is performing normal observations (with Synoptic and Shock modes at perihelion). STIX and in-situ instruments are in normal or burst modes (scheduled or triggered). Objectives that can be addressed with this SOOP include CME structure and evolution, how the Sun's magnetic fields link into space, heating in flaring loops vs heating in active regions, properties of the magnetic field at high solar latitudes etc. This SOOP is specifically designed to be low-resource and can be run even under the most challenging telemetry constraints. In that sense, this SOOP describes the minimum of performance that we can get from the remote-sensing payload during the remote-sensing windows.

4.5. L_FULL_LRES_MCAD_Probe-Quadrature: specific SOOP for Parker Solar Probe quadratures

This SOOP is designed to study the corona while Parker Solar Probe is in quadrature with Solar Orbiter, that is the Probe-Sun-Orbiter angle is of the order of 90°. The default duration of this SOOP is 3 days, the spacecraft points to the solar disk centre and the in-situ triggers are enabled. PHI and EUI provide context, while Metis and SoloHI are leading this SOOP (i.e. they are the main instruments of this SOOP) by providing imagery of the solar wind that is expected to be encountered by the Parker Solar Probe. Medium cadence is considered to be enough for this SOOP: PHI will be using the FDT telescope observing the full field-of-view with a 6-hours cadence, EUI will be using the synoptic mode of FSI, while Metis will be using its special PROBE mode with a cadence ranging between 1 and 10 minutes depending on the heliocentric distance. SoloHI will also adapt its mode depending on the distance.

4.6. L_FULL_MRES_MCAD_CME-SEPs: Solar Energetic Particles (SEPs) accelerated by CMEs

In order to understand whether and how the in-situ properties of the solar energetic particles (SEPs) are linked to the coronal mass ejections (CMEs) and shocks, we need to observe continuously with the in-situ payload together with SoloHI and Metis instruments observing the CMEs as they propagate out of the corona. The typical duration of this SOOP is 10 days with a disk center pointing and all in-situ and Metis triggers enabled. SoloHI will be observing in its Shock or Synoptic modes, Metis will be in the standard mode GLOBAL or in the specially designed mode CMEOBS. The FSI imager of EUI will be observing in its synoptic mode with the default cadence of 10 minutes or down to 5 minutes when possible for specific objectives. PHI and SPICE are not included in this SOOP. If possible, we will run this SOOP when the Parker Solar Probe is within 0.25 AU and optimally to the east of Solar Orbiter.

4.7. L_FULL_HRES_LCAD_MagnFieldConfig: studying the large scale structure of the interplanetary magnetic field

Solar Orbiter will acquire magnetograms of the Sun's polar regions with PHI, while simultaneously measuring the magnetic field in space at a range of locations, making more precise measurements of the reversal of the solar magnetic field and its effects on the heliosphere. This SOOP has been mainly designed to understand how the solar field reversal affects the coronal and heliospheric magnetic fields. For this, we will measure the polarity and the variation of large scale structures of the Sun's magnetic field in interplanetary space close to the Sun as it progresses from solar minimum towards maximum and the global field reverses. Even though part of this objective can be addressed with in-situ only measurements, it would make more sense to have access to full disk remote sensing observations to properly understand how the changes observed in situ are linked to the overall changes of the Sun's surface magnetic field. For this, we need long-term observations at synoptic modes (for telemetry reasons), by targeting the full disk for both photospheric and coronal fields. Since such (low resolution) observations already exist from Earth, it would mostly be interesting to observe when Solar Orbiter is at the far side of the Sun or in the extended periods when the spacecraft is moving towards/away from Earth, at either side of the Sun. In the latter case it would be useful to take observations that are regularly spaced in solar longitude rather than in time. This should also be repeated for different latitudes. Since in-situ MAG measurements are key for this objective, good statistics during EMC Quiet periods are required. PHI's FDT will observe at highest spatial resolution (2Kx2K detector) with a cadence of once or twice per day. EUI's FSI will also observe at highest spatial resolution (3Kx3K detector) at the same cadence. Metis will observe with its synoptic programme for magnetic field structure (GLOBAL and/or LT-CONFIG modes).

4.8. L_FULL_HRES_MCAD_Coronal-He-Abundance: linking helium abundance from the corona to the solar wind

Compared to its value in the solar convective envelope, the helium abundance deduced from in-situ measurements of the fast and slow solar wind has long been known to be depleted relative to hydrogen, with occasional transient exceptions (Bochsler 1998). In the slow solar wind, the degree of depletion has more recently been shown to depend upon the wind speed and the level of solar activity (Aellig et al. 2001). Measurements of the helium abundance in the corona, associated to measurements of the coronal outflow velocity, will provide evidence of the degree of correlation between wind speed and helium abundance and allow identification of the source regions of the slow wind streams with different helium abundance. During the mission phases when the spacecraft is at the closest perihelia of 0.28 AU, it will be in near-corotation with the Sun and will be able to continuously observe individual regions, free from projection complications, over longer periods than are possible from Earth orbit. During this near-corotation, the intrinsic evolution of magnetic topology will be observed and thus its influence on the wind parameters (such as wind outflow velocity and helium abundance) will be directly assessed. The abundance can be derived from simultaneous observations of the resonantly scattered component of singly ionised helium by EUI/FSI in its 30.4 nm channel and of that of neutral hydrogen by Metis in Lyα (121.6 nm). For EUI the FSI synoptic mode with 20 minutes cadence will be used and we might also use the EUI occulter (the FSI filter has a position in which an occulting disk blocks the light coming from the solar disk, so that only the UV light coming from the low corona can reach the detector). For Metis, we will use the modes MAGTOP and WIND with a 20 minutes cadence for a duration of at least 2 hours in order to obtain global maps of neutral hydrogen Lyα intensity, electron density and the outflow velocity. Useful contributions can be given by SPICE (Composition Mapping mode), mapping the near-surface elemental abundances, including that of helium, which constitutes a reference for establishing abundance variations in the wind. PHI can also contribute with a 6-hour cadence synoptic mode, providing data suitable for coronal magnetic field extrapolations. SoloHI will measure the solar wind speed above the potential source region in coordination with Metis. SWA will measure the α/p density ratio. This SOOP will in principle be scheduled when the spacecraft is inside 0.45-0.5 AU, which is an optimal distance for the EUI/FSI occulter or at perihelion for a reduced rotation of the Sun relative to the spacecraft.

4.9. L_FULL_HRES_HCAD_Eruption-Watch

This SOOP is designed to catch eruptive events and contribute to the understanding of a coronal mass ejection initiation. It will be observing the full solar disk with high spatial resolution and high temporal cadence for a typical duration of one day. EUI will be in the Global Eruptive Event mode during the whole day, but it will only prioritise the data of one or two events due to telemetry limitations (e.g. data corresponding to 2 hours of the day). Metis' standard mode GLOBAL will be used together with the CMEOBS mode for a duration of at least one hour, when triggered after a CME flag rises. PHI's FDT will also be observing at the highest spatial resolution with a cadence of 2 to 5 minutes and a data selection will be needed as for EUI. SoloHI will perform a combination of the Shock and Synoptic modes, each for half of the total duration of the SOOP. For SPICE we can either run the mode of Composition Mapping or alternatively start with the Dynamics mode and then with the Waves mode (in an attempt to catch EUV waves) if we cannot off-point from the disk-centre. STIX and the in-situ instruments will be in normal mode, with all triggers enabled. Because of the EUI and PHI internal memory limitations and the high-resolution and high-cadence needed for this SOOP, we are limited to a duration of one day, which should optimally be run at perihelion throughout the solar cycle. It is preferred to be in quadrature with Earth (i.e. the angle between Earth-Sun-Orbiter being of the order of 90°), so that L1 and Earth-based assets can measure the resulting ICME in situ.

4.10. L_FULL_HRES_HCAD_Coronal-Dynamics

This SOOP is aimed at observing structures in the outer corona and linking them to the heliosphere observed in-situ. The Metis and SoloHI instruments are leading this SOOP, while the in-situ payload provides continuous observations. Synoptic support is provided from other full disk remote-sensing instruments (PHI and EUI). The typical duration of this SOOP is one day. SoloHI would operate in a combination of the high-cadence Turbulence mode and the Synoptic mode. Metis would run a generic mode like WIND interleaved with FLUCTS for a typical duration of 1 hour per day. When this is run close to the perihelion, the disk centre pointing is preferred in order for Metis to be able to operate. When off-pointing to a limb active region is possible, SPICE can optionally contribute with the Limb mode. Objectives that can be covered with this SOOP are tracing of streamer blobs and other structures through the outer corona and the heliosphere, study of the structure and evolution of streamers, coronal shocks and associated heating, dissipation and acceleration mechanisms. When possible, radial alignments or quadratures with Parker Solar Probe and/or Earth assets would be very beneficial.

4.11. L_SMALL_MRES_MCAD_Ballistic-Connection

The above objectives of tracing streamer blobs or other structures through the outer corona, can also be addressed with this specific SOOP, for which the spacecraft points at the modelled ballistic connection point. The difference to the previous SOOP is mainly that we need to off-point to the region on the Sun that is most likely connected ballistically to the spacecraft, according to the solar wind models. In this case we cannot always use Metis. This SOOP can run in medium resolution and cadence for a typical duration of 3 days. EUI/FSI will be in Synoptic mode, while EUI/HRI (High Resolution Imagers) can observe in Coronal Hole mode at a cadence of roughly 15 minutes, adjusted to be equal to the cadence of PHI's High Resolution Telescope (HRT). SoloHI will use its nominal synoptic perihelion program. SPICE composition and dynamics modes will be interleaved. The in-situ instruments will be in normal mode with the regular scheduled bursts and the possibility of triggered burst.

4.12. L_SMALL_MRES_MCAD_Connection-Mosaic

This SOOP is designed to let the high-resolution remote-sensing observations cover a wider area than normal, in particular the SPICE field-of-view. This SOOP is to be used in particular with a mosaic of spacecraft pointings (see SPICE Consortium et al. 2020 in this issue for details), though it does not necessarily need to be. Alternatively it could be used when we point for a limited amount of time (few hours typically) to the most likely connectivity point, within a mainly sun-disk-centred observation period. The SPICE instrument, which needs 30 minutes for producing a composition map, leads this SOOP with a typical duration of 3 hours. The details on the slit size, exposure time, number of positions, field of view, number of repetitions and the lines used can be found on the SAP pages of the Solar Orbiter science website for each objective. PHI/HRT and EUI/HRI will be producing 2-3 images for each SPICE map, which corresponds to a typical cadence of 10-15 minutes. Synoptic observations will also be provided by EUI/FSI. The Metis instrument will in general be in safe mode with its door closed, unless the spacecraft is far enough from the Sun (see Antonucci et al. (2020) for details about the operational constraints of Metis). In particular, the door of the Metis instrument must be closed when the spacecraft is pointing off Sun centre, called 'off-pointing', since the coronagraph is designed specifically to operate in Sun-centred position. If this is not the case, and sunlight enters the instrument from other angles, there are risks of both overheating the instrument and damaging the sensors. However the door can be open during off-pointing if at the same time the spacecraft is far enough from the Sun, approximately farther than 0.55 AU.) This SOOP is covering crucial objectives of the Solar Orbiter mission related to the connection of the plasma that we observe in situ to the features observed on the solar disk. For example, to trace streamer blobs (as already described in SOOPs L_SMALL_MRES_MCAD_Ballistic-Connection and L_FULL_HRES_HCAD_Coronal-Dynamics), we will perform a North-South mosaic (thus eliminating latitudinal uncertainty) centred on the most likely connection point as defined by state-of-the-art models. The way that theoretical models and simulations will be supporting the Solar Orbiter operations is described in Rouillard et al. (2020). We can equally benefit from Parker Solar Probe observations as well as observations from Earth (e.g. when in quadrature with Earth we can have SoloHI images of blobs directed to Earth or images taken from Earth of blobs that are expected to reach Solar Orbiter). Another objective that could benefit from this SOOP is the identification of the possible sources of the slow solar wind, by doing, for example, mosaics of a larger area around an active region, again using modelling to identify the best possible candidate. This SOOP is expected to run many times in different phases of the solar cycle and near the perihelion for a maximum chance of linking the plasma to its source regions.

4.13. L_SMALL_HRES_HCAD_Fast-Wind

In order to identify the sources of the fast solar wind, it is not sufficient to perform a remote-sensing characterisation of the corona, e.g. by pointing to the center of a coronal hole and its boundaries. It is also important to observe the fast wind in situ and link it back to its origin. In order for the in-situ measurements to be likely to be connected to the remote-sensing observations, we have to choose a coronal hole near the west limb, and observe it from a location close to the Sun and preferably during high-latitude windows. This could be done during different parts of the orbit. An example could be to observe during a window that precedes perihelion to obtain the overall context of the solar disk and then observe during the perihelion for connectivity. Polar coronal holes could also be observed with Metis from the equatorial plane (no need for high-latitude observing windows, since it can be observed in the plane-of-sky above the hole). In this case, however, there is less chance of doing linkage science. Low-latitude coronal holes should also be observed for intermediate speed outflow. Even if this has a lower priority (in terms of this specific science goal), it should not be neglected since this is the typical solar wind observed at Earth. The minimum and declining phase of the solar activity cycle is preferable for observing polar coronal holes. Low-latitude coronal holes can be observed at any phase of the cycle, but the probability to be at the right longitude at perihelion is low.

The required observations include EUI/HRI in Coronal Hole mode with 1 minute of cadence, during 1-2 hours and 12 hours at lower cadence, PHI observes at high resolution at 1 min cadence, while SPICE provides FIP and velocity maps running for several hours 3 times per day. The in-situ instruments will be in normal mode for the connection and burst modes for more details. MAG Burst mode is required for ion cyclotron wave identification to distinguish from different acceleration and heating mechanisms as well as small scale changes. Recent analysis of Helios data shows velocity changes with jet-like features probably well below the 40 s cadence. We would, therefore, need 3-D distributions at 1 s scales in order to determine the properties inside and outside these features.

The possible remote-sensing targets should include wide regions of well extended coronal holes, as well as smaller regions for focusing on the different candidate sources of the fast wind, e.g. small, cool coronal loops, open magnetic funnels at the base of coronal holes, spicules with short lifetimes and macro-spicules within coronal holes, polar plumes, interplume regions, coronal hole boundaries etc.

4.14. L_SMALL_HRES_HCAD_Slow-Wind-Connection

Identifying the sources of the slow solar wind is expected to be one of the most challenging scientific goals of Solar Orbiter. As for all wind origin objectives, we need to compare the elemental composition, temperatures and charge states of coronal features to the in-situ ones, adopting different strategies for different kinds of structures (e.g. helmet streamers, loops near active regions, streamer cores, edges of active regions etc.). This SOOP aims at catching with the remote-sensing instruments the dynamics of an open-closed field boundary, which will then be crossed by the spacecraft and observed in situ. High-resolution remote-sensing observations are required to catch the dynamics and since specific target pointing is needed, we will also make use of the best available models for predicting the best candidate region to which the spacecraft is likely connected. A typical duration for this SOOP is 3 days. EUI coronal hole mode will be used at a cadence of 1 minute together with a synoptic mode of FSI. PHI will acquire regularly spaced HRT data at medium to high resolution (600 s default cadence, but 1 hour cadence would also be sufficient for studying interchange reconnection at high resolution). PHI will also make use of the Low-Latency magnetograms (Solanki et al. 2020) in order to better identify the most interesting periods that would be selected for downlink. SPICE is central to this objective using a combination of the Dynamics mode and of Composition Mapping rasters. The raster area will be optimised to make sure that the open-closed field boundaries are captured and the lines will be chosen according to the type of target.

4.15. L_BOTH_MRES_MCAD_Farside-Connection

Just as for the SOOP L_SMALL_HRES_HCAD_Slow-Wind-Connection, we aim at observing the region to which the spacecraft is likely to be connected to address all connectivity science goals, both for fast and slow solar wind sources. When the spacecraft is at the far side of the Sun as seen from Earth, we additionally need imagery of the full solar disk with the PHI/FDT synoptic program at low cadence. When possible, a higher spatial resolution is preferred. All other instruments will follow the same strategy as in L_SMALL_HRES_HCAD_Slow-Wind-Connection.

4.16. L_BOTH_LRES_MCAD_Pole-to-Pole

This SOOP is designed to be used as a whole or half-orbit synoptic campaign that scans the Sun from high latitudes in one hemisphere to the other. For that reason, it will mainly be used later in the nominal mission phase when the spacecraft reaches inclinations of at least 15 degrees. This SOOP resembles very much the coronal synoptic L_FULL_LRES_MCAD_Coronal-Synoptic, but this time SPICE is necessary as well. The default duration of this SOOP is 10 days with the imagers pointing mainly to the disk centre. EUI makes use of the FSI telescope in its synoptic mode with a cadence around 10 minutes. Metis uses the GLOBAL or LT-CONFIG modes to observe large scale coronal structures and the CMEOBS special mode whenever triggered by a CME detection. PHI is observing with the FDT telescope synoptic mode, but HRT can also be used at a medium cadence especially at higher latitudes for polar magnetic field observations. SoloHI is performing synoptic observations. STIX and in-situ instruments are in normal or burst modes (scheduled or triggered). SPICE will be scanning many latitudes performing a Composition Mapping raster for consistently mapping the whole area and followed by multiple instances of the CME Watch mode.

4.17. L_BOTH_MRES_MCAD_Flare-SEPs

This SOOP is aimed at understanding the properties and dynamics of solar energetic particles (SEPs) in relation to flare events. EUI and STIX are leading this SOOP, while the in-situ payload provides continuous observations. Synoptic support from other full disk remote-sensing instruments is provided. Disk centre pointing is preferred. For most of the science objectives SPICE is good to have, but as the SEP events are rather rare, it is not feasible to know which particular region should be observed. However, since all other instruments are involved, SPICE will probably be observing anyway. Because of the difficulty to predict the events, it is preferable not to observe with a high-resolution or high-cadence for EUI and PHI (5-10 min cadence is considered to be sufficient), except when such observations (at 1 minute cadence) are triggered by a STIX flag whenever the flare happens to be inside the EUI/HRI field-of-view. Metis special mode CMEOBS can also be triggered by a CME flag and observe for a minimum time of 1 hour with a cadence of 1 minute.

4.18. L_BOTH_HRES_LCAD_CH-Boundary-Expansion

This SOOP is similar to L_SMALL_HRES_HCAD_Slow-Wind-Connection, but it specifically aims to study over-expanded coronal holes boundaries as possible sources of the slow solar wind. This requires a different PHI mode and different SPICE observations. Regularly spaced PHI/FDT images are required with a cadence of 6 hours throughout a remote-sensing window. For SPICE, the raster area should be optimised to make sure the open-closed field boundary is captured. For this reason, 6 rasters are planned at perihelion at highest possible resolution. A full north-south raster will only be done for extended holes, otherwise it is enough to point at the boundaries. For stable structures, we would plan 3-4 days of standard observations together with 1 day of mosaic observations.

4.19. L_BOTH_HRES_HCAD_Major-Flare

This SOOP aims to perform high-resolution and high-cadence observations of a major flare to study the event in unprecedented detail, ideally at perihelion and pointing to the most promising region for a typical duration of 4 days. It is suggested to plan the first instance of this SOOP in the ascending phase of the solar cycle. Subsequent runs of the SOOP are suggested until a major flare is successfully captured in high cadence and high spatial resolution. A special opportunity could arise when Solar Orbiter and Earth are both connected to a same, promising Active Region (either magnetically or ballistically). It can potentially be combined with observations from DKIST and other Earth-based or near-Earth observatories and instruments. EUI/HRI observes in highest spatial resolution with 1 s cadence and EUI/FSI at 1 min cadence. To avoid limiting the telemetry for the entire orbit, the triggers should allow to only select the most interesting two hours for downlink. The FSI images allow to study potential EUV waves associated with the flare. STIX observes in its normal mode. SPICE is in Dynamics mode with the raster centered at the centre of EUI. A SPICE CME watch mode could be added after a number of repeats of this SOOP. PHI/FDT observations are used for context and extrapolations. SoloHI in normal mode provides heliospheric imaging of a potential CME associated with the flare. All in-situ instruments observe in normal mode for catching signatures of potential CMEs or SEPs.

4.20. R_FULL_LRES_LCAD_Transition-Corona

The large scale structure of the low corona is determined by active regions, filament channels and coronal holes whose presence and location have a clear evolution over the solar cycle. Higher up in the corona, active regions and filaments are over-arched by pseudo streamers and streamers that fade into the heliospheric plasma sheet. This magnetic connection region between corona-heliosphere is of particular physical interest because it is there that the structuring of the magnetic field is taken over by the plasma outflow. This intermediate region, or transition corona (say 1 to 3 solar radii above the solar limb) is poorly studied as it corresponds to the field-of-view gap between most EUV imagers and coronagraphs. Coronal/heliospheric simulation codes such as ENLIL or EUHFORIA typically bypass the complexity in this region completely by ad hoc empirical laws to obtain 'coronal' boundary conditions at 0.1 solar radii. When trying to determine the coronal footpoint of features observed by the in-situ instruments, the transition corona introduces significant uncertainty as the Parker-spiral type of mapping has to be connected to magnetic field extrapolations from the photosphere. Deciphering this connection is thus of primordial importance for Solar Orbiter connection science, but the transition corona itself might also harbour interesting features. The purpose of this SOOP is to obtain a full-Sun (360 degree) structure of the transition corona involving in first instance PHI/FDT (for magnetic extrapolations), EUI/FSI (optionally with occulter) and Metis. The basic observation unit is one image set per day from all three telescopes. This basic observation unit has to be repeated as many subsequent days as possible as to obtain a full-Sun 360 degree coverage. This can be achieved by combining three remote-sensing windows, by joint observations from Earth-based instruments and — if needed — observations outside of the remote sensing windows should be considered too (see section 6). The 360 degree total observation should be done at least once near solar minimum and once near solar maximum. This SOOP does not require perihelion for the highest resolution nor any off-pointings.

4.21. R_FULL_LRES_HCAD_Global-Helioseismology

This SOOP is designed for global helioseismology studies using only PHI/FDT. Solar Orbiter will provide the first opportunity to implement the novel technique of stereoscopic helioseismology to probe flows and structural heterogeneities deep in the convection zone, even reaching down to the tachocline. Combining Solar Orbiter observations with ground- or space-based helioseismic observations from 1 AU (e.g., GONG or SDO) will open new windows into the Sun. Looking at the Sun from two distinct viewing angles will increase the observed fraction of the Sun's surface and will benefit global helioseismology because the modes of oscillation will be easier to disentangle due to the reduction of spatial leaks. With stereoscopic helioseismology, new acoustic ray paths can be taken into account to probe deeper layers in the interior, including the bottom of the convection zone. PHI/FDT would observe at 1 minute cadence, but only processing the line-of-sight velocities. In order to reduce telemetry, images would be compressed by binning to 2x2 (corresponding to a resolution of 10-15 Mm when the spacecraft is at perihelion) or cropping when farther away from the Sun. Higher compression may possibly be acceptable for far side imaging. For deep focusing we could run this SOOP for several days (e.g. 3 days). For far side imaging to detect modes passing through the solar core we need to observe as long as possible, of the order of 60 days. Such long observations are not yet part of the science plan and their feasibility needs to be assessed taking into account the operational limitations.

4.22. R_FULL_HRES_HCAD_Density-Fluctuations

This SOOP only involves remote-sensing instruments and is designed to study the density fluctuations in the extended corona as a function of the outflow velocity of the solar wind while evolving in the heliosphere. Metis and SoloHI are leading this SOOP with the Metis FLUCTS mode for 1 hour (with cadence ranging from 1-20s), then MAGTOP (5-20 minutes cadence) for several hours to several days. Preferably the SOOP would also be repeated for 8 hours during the two following remote-sensing windows. PHI/FDT would be observing at 6-hour cadence to provide context. Long exposures for EUI/FSI synoptic mode are needed to get good signal-to-noise ratio where it overlaps with Metis. SPICE can optionally participate before and after the main observations, while off-pointing to an active region at the limb.

4.23. R_SMALL_MRES_MCAD_AR-Long-Term

This remote-sensing SOOP will study the decay process of active regions. It needs to run for a typical duration of 15 days, continuously pointing to an active region, to fully catch the dispersion of that region. PHI is leading this SOOP with full field-of-view observations (FDT) at a cadence of 10 minutes. SPICE Dynamics mode will be used. EUI will match the field-of-view, resolution and cadence of PHI. Metis can potentially provide context data before and after this SOOP.

4.24. R_SMALL_HRES_LCAD_Composition-vs-Height

This SOOP will map the abundance of minor ions as a function of height in the corona to distinguish between slow and fast solar wind. The observation target can be a boundary of a streamer or an active region on the limb. SPICE is leading this SOOP with the Composition Mapping mode. EUI will provide context at higher cadence than SPICE in order to interpret the SPICE composition map. PHI is needed for context magnetic field, but mainly before or after the SPICE observations since the target will be on the solar limb. Since Metis cannot participate at limb pointing (because it cannot off-point), it would provide context observations before the main observations. A typical duration of this SOOP is of the order of several hours, run twice. This can be done at any remote-sensing window, but perihelion is preferred for active region observations or a distance greater than 0.55 AU for streamer observations (since this is the distance beyond which Metis can off-point).

4.25. R_SMALL_HRES_LCAD_Fine-Scale-Structure

This SOOP studies the finest scales of active regions or other solar features. This SOOP needs to be at the highest spatial resolution, but low cadence is sufficient since, in this case, we are not interested in the dynamics. A perihelion window is preferred for these observations. EUI/HRI will use the Quiet Sun and Active Region modes at a cadence of 10 minutes and at the highest resolution. PHI/HRT would match the cadence and resolution of EUI. Depending on the science goal (e.g. for waves and/or temperature structure discrimination), SPICE may be in one of its high resolution modes, e.g. Dynamics. A typical duration is 12 hours. Metis may take part to provide off-limb observations when close to the Sun, e.g. for studying plumes.

4.26. R_SMALL_HRES_MCAD_Polar-Observations

This SOOP is designed to address the objectives relevant to the polar magnetic field, which do not necessarily rely on the highest resolution and cadence of PHI nor on all five physical parameters that PHI can return. The typical cadence for PHI and EUI is 2-5 minutes. SPICE, SoloHI and STIX would be observing using their nominal mode. Metis would have its door closed for safety reasons due to off-pointing.

4.27. R_SMALL_HRES_HCAD_Photospheric-Dynamics-Structure

This SOOP is designed to study the fine structure of the photosphere. It is a burst mode of one hour for EUI (HRI at 1-30 s cadence), PHI (HRT at 1 minute cadence) and SPICE. The instruments Metis, SoloHI and STIX do not participate in this SOOP. Many objectives will need this SOOP such as the full characterisation of photospheric magnetic fields, photospheric reconnection, high-latitude magnetic field structures, flux appearance modes and interaction in Quiet Sun, granulation and oscillations, limb stereoscopy of magnetic fields etc. Due to the very high space resolution and high time cadence, this SOOP is very demanding from the telemetry point of view. For this reason, it can only be run for short times and only when the onboard memory has enough storage capability left.

4.28. R_SMALL_HRES_HCAD_AR-Dynamics

This SOOP will study the dynamics of a complex active region and its link to the ^{3}He-rich SEPs production. It can also track a region for exploring the initiation of an active region. It will make use of the highest resolution capabilities without binning. EUI will run its Active Region mode and PHI/HRT. Due to telemetry limitations, we would only downlink one hour of this data around the event. STIX would have its triggers active. In principle, EPD is also needed for detecting the ^{3}He-rich SEP events.

4.29. R_SMALL_HRES_HCAD_PDF-Mosaic

This SOOP observes the probability density function of the magnetic elements. Ideally it would scan the solar radius with a mosaic made up of 3-4 different positions from the equator to a pole. SPICE would require 30 minutes at each dwell position with at least 10 images per dwell taken by PHI/HRT.

4.30. R_SMALL_HRES_HCAD_RS-Burst

This SOOP describes a coordinated observation of high-resolution remote-sensing instruments (EUI, PHI and SPICE), running at highest resolution and variable, but high cadence, for a short period of time (of the order of 10 minutes). As a planning scenario, we propose to run this SOOP at every perihelion window where we have some extra telemetry to spare, or where the campaign would fit without sacrificing too much of the rest of the orbit. This SOOP can be run for different targets, also at plain disk centre, as it is aimed to discover new physical phenomena and compare high cadence dynamics in all kinds of solar regions. EUI can use various HRI modes, including its Discovery mode designed to discover solar variations with periods less than 10 seconds.

4.31. R_SMALL_HRES_HCAD_Wave-Stereoscopy

The scientific aim is to characterise the properties of waves in the photosphere and their coupling with the atmosphere. Waves are one clear mechanism for transferring energy from the photosphere to the chromosphere and corona. Measuring the properties of the waves requires, in part, a determination of the velocity field. The line-of-sight velocity component can be determined at different heights in the atmosphere by observing Doppler shifts in different spectral lines. From Earth's vantage point we have high-resolution ground-based, balloon-borne, and satellite instruments. Determining the horizontal velocity has previously relied on using correlation tracking of intensity variations and rely on the questionable assumption that the changes in location of the brightness fluctuations reflect the actual velocity. Solar Orbiter's orbit and capability to measure Doppler velocities, in conjunction with existing and upcoming ground-based or near-earth observatories, offers the unique chance to directly measure two components of the velocity field using the Doppler effect.

High-resolution co-temporal measurements including Doppler velocity maps from Solar Orbiter as well as ground and near-Earth observatories are required. In particular the ground-based and near-Earth observations should include high resolution Doppler images in the same line (with a higher cadence than that of Solar Orbiter), as well as lines sampling different heights of the atmosphere. Co-observation with IRIS (De Pontieu et al. 2014) would be desirable. During the observing period, the Earth-Sun-Solar Orbiter angle should be between 30 and 60 degrees, a range which represents a compromise between determining the two components of the velocity field and allowing magnetic features, which can act as wave guides, to be partially resolved.

For ease of understanding the connection between the different heights, the observations would best be performed at the centre of the disk as observed from Earth (where observations over different wavelengths are possible). Because also the achievable cadence will be higher on ground than with PHI, it is preferable to select targets which are closer to disk centre as seen from Earth and at higher heliographic angles as seen from Solar Orbiter. The highest possible cadence is desirable, and a shorter time series (down to 30 minutes of Solar Orbiter observations) would still allow the scientific objectives to be met. (The ground-based and near-Earth observations should be made for a period of 90 minutes centred on the 30 minute Solar Orbiter observations). However, in order to guarantee reliable conditions (seeing) at the coordinating ground-based observing facility (e.g. DKIST) a continuous high-cadence observation period of several hours is required. High resolution context magnetic maps from Solar Orbiter immediately before and after the 30 minute observing window are required to provide context and aid co-alignment. A second observational campaign of an area 45° from disk centre, with an Earth-Sun-SO angle of 90°, would be desirable.

4.32. R_SMALL_HRES_HCAD_Ephemeral

This SOOP is designed to study the emergence, diffusion and decay of ephemeral regions near the poles and below high-latitude coronal holes. PHI/HRT would observe half of the field-of-view with a cadence of 1-2 minutes at the highest resolution. EUI would match the field-of-view and cadence of PHI. SPICE would produce composition maps.

4.33. R_BOTH_HRES_HCAD_Nanoflares

This SOOP aims to detect and determine systematic differences of nanoflares (e.g. cadence, strength, location, magnetic field configuration) in different regions, e.g. quiet Sun, active regions and coronal holes, but also any other target region in-between. Determining differences of the nanoflare characteristics, e.g. occurrence rate, strength, exact location, along with the field configuration is crucial for our full understanding of the role of the nanoflares in the corona heating. In order to study the latitude distribution of the nanoflares, this SOOP should be run with some off-pointing (but not too much because of projection effects). The default SOOP duration is one hour for telemetry reasons since EUI/HRI is at high-cadence (1 second) and EUI/FSI at medium cadence (1 minute). If longer observation time is needed, this SOOP can be run with up to 10 s cadence. PHI/HRT observations are used for context and information of possible changes of the magnetic field orientation in high resolution. Metis FLUCTS mode is equally needed with 1 s cadence and can be followed by the mode observing total brightness fluctuations with a typical cadence of 20 s. SPICE observes with an alternation of its Dynamics and Waves modes in 5 s cadence. STIX is in normal mode.

4.34. R_BOTH_HRES_HCAD_Filaments

This SOOP is intended to high resolution observations of filaments to study their structure and dynamics. It supports both high and low cadence, depending on structural or dynamic aims. It should preferentially run at perihelion and can potentially be used in quadrature with Earth for coordinated observations with DKIST and other Earth-based or near-Earth observatories and instruments. The default SOOP duration is one hour for telemetry reasons since EUI/HRI is at medium cadence (10-60 s)), but other instruments could observe for a longer period, such as Metis when off-pointing is not needed. PHI/FDT observations are used for context and extrapolations. SPICE observes in the Dynamics mode with the raster centred at the filament.

5. Strategy

One of the main reasons for mission level planning is to make sure that we will have enough opportunities to address all mission's science objectives in an optimal way. More importantly, we need to make sure that if e.g., a unique opportunity exists for a specific science goal at a given date or configuration, this goal should be given priority. From this point of view, priorities have to be given not only based on the importance of the science objective (which is sometimes difficult to judge depending on the interests of the science community that cannot be anticipated with many years in advance), but also on many other circumstances that are detailed below. In order to build the plan, we did not prioritise the objectives – all four objectives and their sub-objectives are equally important –, but we defined an order in the criteria that we use for distributing the different SOOPs throughout the mission timeline of the nominal and extended mission phases. The overarching goal of the mission is to connect remote-sensing observations of the solar disk with in-situ measurements (e.g., for CMEs, solar wind) and this takes priority over everything else, whenever possible. These goals are usually called 'connection-', 'connectivity-' or 'linkage-' science and are thoroughly detailed in Müller et al. (2020). Except for this, the criteria that we use are detailed below in order of implementation. The implementation itself (i.e. the details of which SOOP is scheduled when) is out of the scope of the present paper. However we describe an implementation example in the next section for illustrative purposes only.

5.1. Criterion 1: Best resolution remote-sensing data at different perihelia through the mission

We schedule a remote-sensing burst SOOP (R_SMALL_HRES_HCAD_RSburst) whenever we have a perihelion at a time of good communications with the spacecraft, i.e. close to Earth or when Solar Orbiter is moving towards Earth. We could aim at different types of targets or even plain disk centre to discover new physical phenomena in Solar Orbiter's highest cadence data, also possibly in unexpected locations. This campaign would serve several science goals that need very high cadence, need perihelion observations, and are aiming at different types of regions. Even if off-pointing is not possible, this campaign could still be useful to be run on the Sun-disk centre region. The SOOP under consideration is telemetry demanding, so we need good telemetry at the time of the perihelion or right afterwards. Alternatively, for some science objectives, e.g. study of the effects of energetic particles propagating downward in the chromosphere, it may be beneficial to schedule a few short sequences of the above SOOP in a remote-sensing window (or a series of remote-sensing windows), to enhance the chances of catching energetic particles instead of dedicating all telemetry for high-resolution high-cadence observations during a few hours of the window.

5.2. Criterion 2: Objectives requiring Metis & SoloHI to observe Earth-directed transients

The objectives relative to the structure and propagation of CMEs and blobs ideally need Solar Orbiter and Earth in quadrature with SoloHI looking towards Earth, so Solar Orbiter at GSE -Y (i.e. the angle between Earth-Sun-Orbiter being of the order of 90°. GSE is the Geocentric Solar Ecliptic system: it has its X axis towards the Sun and its Z axis perpendicular to the plane of the Earth's orbit around the Sun. This system has the advantage of being fixed with respect to the Earth-Sun line.) This criterion can preferably be applied at perihelia but also during high-latitude windows. Alternatively, instead of quadrature, it will be interesting to observe at 45-degrees separation angle. The SOOPs that are most suitable to run during these times are: L_FULL_HRES_HCAD_Coronal_Dynamics (focused on the off-limb corona up to Earth) and L_FULL_HRES_HCAD_Eruption_Watch. The second SOOP is more telemetry demanding but helpful if the CME happens to come towards Solar Orbiter: then it can be viewed sideways from Earth. Remote-sensing windows that fall close to equinox could also be preferred since Earth-directed CMEs (and southward IMF solar wind-magnetosphere coupling in general) are more geoeffective. Other SOOPs that should at least be run a few times at quadrature are L_FULL_HRES_MCAD_CME_SEPs and L_FULL_MRES_MCAD_Flare_SEPs (this one with SoloHI towards Earth). Even though these can be run at all times, some of the related sub-objectives benefit from quadrature with Earth, so that Earth-linked observatories can observe the structure of the CME heading towards Solar Orbiter.

5.3. Criterion 3: Slow solar wind connection science requiring Earth context for modelling prior to a remote-sensing window

As already discussed, connection science objectives constitute the basic goal of the Solar Orbiter mission. For planning purposes, we consider two very different types of connection science campaigns: during the solar minimum and during the rest of the solar cycle.

During solar minimum. The magnetic field configuration is much simpler than during the rest of the solar cycle, with slow solar wind coming from the streamer belt. In addition, during the early orbits of the mission, Solar Orbiter will stay close to the ecliptic. If PHI observes the far side magnetic field in good resolution, and we combine that with the Earth-side magnetic field, the full solar magnetic field configuration can be modelled including the location of the Heliospheric Current Sheet that will determine the hemisphere Solar Orbiter will be connected to. This model could be the ideal starting point to run a longer term (10-20 days) connection SOOP using synoptic data of both in-situ and remote-sensing payload pointed to the most likely connection point. During this campaign, PHI keeps on taking regular full disk magnetograms to update the magnetic field model as we go. The modelling should also improve as Earth and Solar Orbiter see overlapping longitude ranges of the Sun. The relevant SOOPs are L_FULL_HRES_LCAD_MagnFieldConfig for the magnetic field modelling (during the first remote-sensing window), while during the connection observations we will use L_BOTH_MRES_MCAD_Farside_Connection, possibly combined with L_SMALL_MRES_MCAD_Connection_Mosaic.

During the rest of the solar cycle. As the Sun becomes more active, the magnetic field modelling will become more challenging. In these periods, we hope to rely more on Earth observations to get a well-constrained model of the field that Solar Orbiter is going to fly through. If PHI data are restricted or not available, we mainly rely on Earth to produce the model 4 days in advance due to VSTP turn-around loop. For this to happen, we need Solar Orbiter in the GSE sector X<1 and Y<0, i.e., similar orbits than the ones needed for Earth-directed transients above. The further Solar Orbiter moves away from that sector, the more we rely on PHI data to model the most likely connection point. Due to the more complicated and less reliable magnetic field modelling, we may want to use pointing mosaics to establish the most likely connection point using the SOOP L_SMALL_MRES_MCAD_Connection_Mosaic. During later orbits, the concatenated perihelion and north windows will span a large range of latitudes over a short period of time. This SOOP will be combined with L_SMALL_HRES_HCAD_Slow-Wind-Connection, involving high resolution and cadence remote-sensing observations to explore source regions in detail, or L_SMALL_MRES_MCAD_Ballistic-connection. If we point at a coronal hole boundary, the SOOP L_BOTH_HRES_LCAD_CH-Boundary-Expansion fits as well.

5.4. Criterion 4: Polar Objectives

The different objectives that require high latitude (e.g., all those that require observing the poles) have to be planned during high-latitude windows and split between objectives that need good telemetry and those that they don't, to find the best suitable schedule.

5.5. Criterion 5: Opportunities for long-term remote-sensing observations

Some science objectives benefit from a longer period of continuous remote-sensing observations, typically in some sort of synoptic mode. A special case of this criterion includes remote-sensing observations that could run from pole to pole with minimal interruption. These observations should be scheduled at times when two RS windows are concatenated or when there is minimal interruption between windows.

5.6. Criterion 6: Fast Wind Connection

The SOOP L_SMALL_HRES_HCAD_Fast_Wind addresses two main science goals that in general need coronal holes as a target. The science objective regarding the sources of the fast solar wind would benefit from a low-latitude (or extended) coronal hole, to increase the chance of connection and to compare the composition of low and fast solar wind streams: this is most likely to happen in the declining phase of the solar cycle (?). We prefer orbits with a fast scan through a big range of latitudes (like the opportunities above for pole-to-pole SOOP - criterion 5). In particular, to address the science goal regarding the origin of jets from polar coronal holes, high latitude windows are preferred to ensure the presence of a well-established polar coronal hole that can be observed in full. Limb pointing from medium latitude is also interesting to get the Doppler velocity component from SPICE combined with EUI for off-limb intensity. Observations from up close would be a big asset as well.

5.7. Criterion 7: Science objectives needing perihelia but lower telemetry requirements

The SOOP L_FULL_MRES_MCAD_Flare-SEPs needs medium telemetry downlink. Some of its sub-objectives require quadrature with Earth (i.e. the angle Earth-Sun-Orbiter being in the order of 90°), so this SOOP is also mentioned above in Criterion 2. The SOOP L_IS_STIX needs low telemetry (in practice this SOOP is likely to run throughout all remote-sensing windows). As the related telemetry needs of these SOOPs are moderate to low, we can schedule them during outbound perihelia, i.e. those where Solar Orbiter is flying away from Earth so downlink performance is decreasing.

5.8. Criterion 8: Global magnetic field reconstruction and symmetry

Remote-sensing windows at the far side of the Sun should be used to have regular, low cadence imaging of magnetic field, to allow global field reconstruction. This goal can be addressed by the SOOP L_FULL_LRES_MCAD_Coronal_Synoptic or L_FULL_HRES_LCAD_MagnFieldConfig. Ideally, we plan these SOOPs at regular far-side windows covering a wide range of phases in the solar cycle. In addition, the same opportunities will allow L_FULL_LRES_MCAD_Coronal_Synoptic to address the study of symmetry of the magnetic field at high-latitude spanning different longitudes.

5.9. Criterion 9: Rest of the objectives and special circumstances

There are many objectives and their related SOOPs that do not fit in the above criteria and have to be planned separately. Some examples can be found in the following paragraphs.

Abundance of minor ions as a function of height in the corona as an indicator of slow or fast wind. This objective will be addressed through the SOOP R_SMALL_HRES_LCAD_Composition_vs_Height. For this goal, we need limb pointing of either an active region (with open field at the edges) on the limb or the boundary of a streamer, so the target can be chosen at the time of VSTP. A perihelion is preferred but not required. Running this SOOP at a slightly larger distance from the Sun could benefit from Metis participation and enough signal in SPICE. Exactly the same requirements are needed for other objectives, e.g. the study of the role of shocks in generating SEPs, which also needs limb pointing during a remote-sensing window above 0.55 AU, so that Metis can contribute to the observations.

Resolve the geometry of fine elemental loop strands. This objective will be addressed by the SOOP R_SMALL_HRES_LCAD_FineScaleStructure. This needs the highest possible resolution at close perihelia, but no high cadence and thus no particularly high telemetry needs. All close perihelia within 0.3 AU seem to be good opportunities for this SOOP.

Study of density fluctuations in the extended corona as a function of the outflow velocity of the solar wind. This objective will be addressed by the SOOP R_FULL_HRES_HCAD_Density_Fluctuations. Metis and SoloHI are leading this SOOP, which is telemetry limited (less than average) except for Metis that needs more telemetry and SoloHI that seems to need its average allocation. This SOOP needs to be repeated at several distances, i.e. at each remote-sensing window, but not too far out for Metis to still see the density fluctuations. 8 hours per window should be enough.

Photospheric dynamics. This objective will be addressed by the SOOP R_SMALL_HRES_HCAD_Photospheric-Dynamics-Structure, which involves high telemetry needs for EUI, PHI and SPICE during a short time (up to 1 hour). We need either perihelion for quiet Sun or close-in high-latitude windows for coronal holes (i.e. North windows). For perihelion windows, we can select the same ones as for the remote-sensing burst above.

Active Region dynamics. The best opportunities to study CME initiation and structure (close to the Sun), are to point to active regions at perihelion with the SOOP R_SMALL_HRES_HCAD_AR-Dynamics. We prefer Earth context for modelling and obtaining CME context.

Latitudinal and longitudinal transport of SEPs. This can be addressed by the SOOP L_FULL_MRES_MCAD_Flare-SEPs. It needs many events, ideally observed from different viewpoints (including Earth and other viewpoints) and different distances (e.g., from Parker Solar Probe or STEREO). It also needs a range of latitudes (some high-latitude windows as well). Ideally, it should be scheduled as many times as possible.

Energy flux in the lower atmosphere. In order to better understand coronal heating we could benefit from coordinated observations with Earth-based (DKIST) and near-Earth (IRIS) facilities, with sets of particular geometries between Solar Orbiter, the target on the Sun, and Earth.

Limb stereoscopy of magnetic fields. This requires perihelion observations at quadrature so that Earth-based and Earth-orbiting assets (specifically the DKIST Fast Solar Polarimeter) can measure the magnetic field from an orthogonal view. The SOOP R_SMALL_HRES_HCAD_Photospheric-Dynamics-Structure seems like the best fit for this.

Objectives that could be enhanced with observations from the Parker Solar Probe Whenever possible coordinated observations with Parker Solar Probe will be planned. Examples of SOOPs that can benefit from such observations are L_FULL_MRES_MCAD_Flare-SEPs, L_IS_SoloHI_STIX and L_FULL_LRES_MCAD_Probe-Quadrature, which requires Parker Solar Probe in quadrature with Solar orbiter (i.e. the angle Probe-Sun-Orbiter being of the order of 90°).

6. Remote-sensing observations outside of the remote-sensing windows

The nominal strategy of remote-sensing windows centred on the perihelia and maximum latitudes maximises the scientific return of the mission during these unique moments, but also implies that the connection between the remote-sensing and the in-situ observations is effective only during about one-sixth of the mission duration. In order to increase the duration of the joint observations, the instruments and operations teams have explored the possibility for the remote-sensing instruments to dedicate a fraction of their telemetry allocation to perform synoptic 'out-of-window' observations that will provide the contextual information necessary to enable connection science throughout orbits, while maintaining a low-resource/low-impact profile and avoid violating the Electro-Magnetic Cleanliness (EMC) requirements of the in-situ instruments. It was found that, while added late to the development of the mission ground segment, out-of-window observations could be made almost resource neutral for the ground operations teams as long as they fit into the low-latency data volume (see Auchere et al. (2020) and Sanchez et al. (2020)). Each remote-sensing instrument therefore designed a 'synoptic' type program that can be run continuously to provide basic contextual information without impacting their core objectives. This includes a highly-compressed 15-min cadence full disk image from EUI/FSI, daily full Sun line-of-sight magnetic field and continuum images from PHI, a 30-min cadence visible light image from Metis, a 30-min cadence 2.5°-wide equatorial and latitudinal swaths from SoloHI, one daily first-ionisation-potential (FIP) bias map from SPICE and nominal observations from STIX. Even though this program is not yet approved by ESA, it is currently under study for an implementation during the nominal mission phase starting in November 2021.

7. An example of Long Term Planning

In this section we describe an example of a 6-months period for which we have applied the above strategy to produce the Long Term Planning. This example covers the period between July 1, 2025 and December 31, 2025. Although this particular period is considered only for illustrative purposes, it is selected as an example on the fact that the spacecraft trajectory is such to enable the implementation of many different SOOPs and to apply the strategy on cases for which an informed choice is needed about the science objectives that are to be addressed. Furthermore this period was exercised within the Solar Orbiter instruments teams and the Science Operations Center before launch producing a detailed observation plan and simulations. The basic results are described in this section, but we note that this is just an example and that the actual plan for these dates might change in the next years following discussions within the Science Working Team.

On the top panel of Fig. 1, we can see the trajectory of the spacecraft between July 1, 2025 and December 31, 2025 in GSE coordinates (the Sun is depicted by the yellow circle at coordinates X=1 AU and Y=1 AU, which is the distance from Earth placed at the origin of the system and depicted by the blue circle). The first day of the trajectory corresponds to the black square on the left of the plot. In this system, Earth is fixed with respect to the Sun. The heliographic latitude and the heliocentric distance are shown on the two bottom panels. The spacecraft

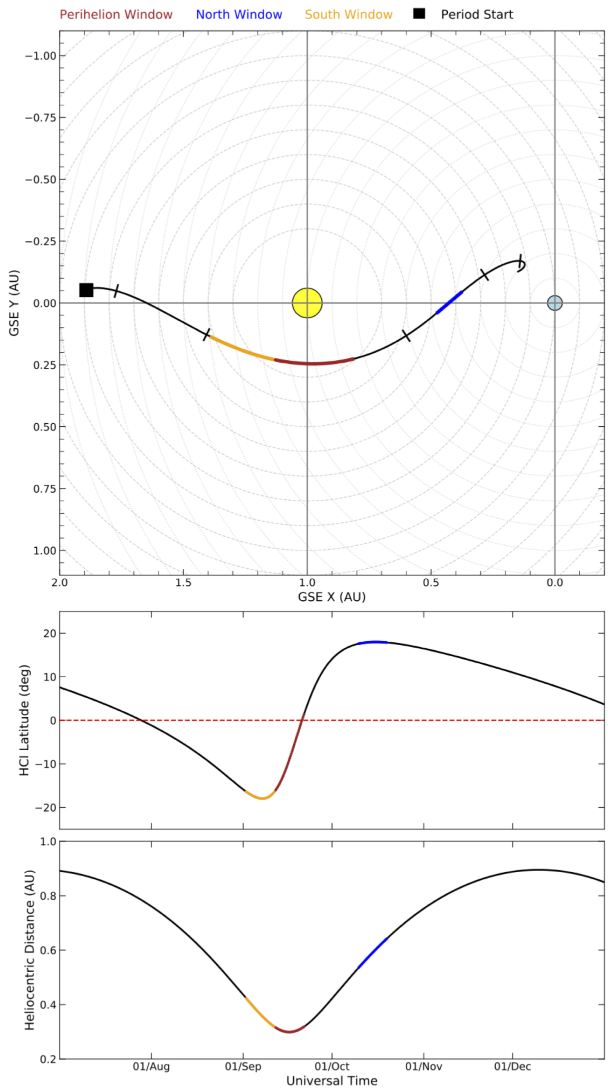

Fig. 1. Top panel: trajectory of the spacecraft between July 1, 2025 and December 31, 2025 in GSE coordinates (the Sun is depicted by the yellow circle at coordinates X=1 AU and Y=1 AU, which is the distance from Earth placed at the origin of the system and depicted by the blue circle). The first day of the trajectory corresponds to the black square on the left of the plot. The two bottom panels show the heliographic latitude and the heliocentric distance. The parts of the curves corresponding to the three different remote-sensing windows are coloured in yellow, red and blue. Black corresponds to periods during which only in-situ instruments are operating without remote-sensing observations.

reaches a latitude of almost 20 degrees and the perihelion is as low as 0.3 AU. The first decision that needs to be taken for every such period is where to place the three 10-days remote-sensing windows (in this example the parts of the curves corresponding to the three different windows are coloured in yellow, red and blue). The parts of the curves that are black correspond to periods during which only in-situ instruments are operating without remote-sensing observations. Usually, the choice is to place one window of 10 days centred at the perihelion (red part) and the two other windows at the highest North (blue) and South (yellow) latitudes. However depending on the science goals that we need to address, a slightly different configuration can be adopted, e.g., by concatenating two of the windows around the perihelion, or even all three windows together if we need to perform continuous remote-sensing observations for 30 consecutive days. In this case, the two first windows have been concatenated, but the configuration is such that they also preserve their original characteristics (the first window is still at high latitude starting with 3 days of delay compared to its default placement and the second one is centred around perihelion). The first window (RSW1) starts on September 5, 2025 and ends on September 14. The second window (RSW2) starts on September 15 and ends on September 24. The third window (RSW3) spans the period between 9 and 19 of October. There is in principle margin to place RSW3 in a different part of the orbit (earlier or later), but it is decided to leave it at the highest latitude, which is the baseline operational scenario. This is particularly important for this specific period, since it is the second period that the spacecraft would be at such a high latitude.

Before examination of the criteria described in the strategy section, we need to thoroughly examine what has already been planned and executed in the previous planning periods. Since this is an example, we just proceed with the following overview of the previous periods and operational assumptions. Prior to this period we will have had seven other planning periods with perihelia around 0.3 AU. The previous period is the first one when the spacecraft would have reached a latitude higher than 15 degrees, so we assume that polar science (criterion 4) will have been tackled during the previous period (first half of 2025) and therefore we do not have to consider it in this example. All previous remote-sensing windows at perihelia will have encompassed quadratures between Solar Orbiter and Earth and there will have been six previous RSWs where at least 90 degrees in longitude of the far side of the Sun will have been visible to Solar Orbiter.

Examination of the first criterion of the strategy described in the previous section requires an assumption on the mass memory fill state at the beginning of the period as well as the telemetry resources. Given the start of the period at conjunction with Earth, it is reasonable to assume that the mass memory is half full since it would contain data from the previous period that had not yet the opportunity to get downlinked. With this assumption, it appears difficult to perform high-resolution and high-cadence observations, so that the first criterion leads us to the conclusion that it is preferable to avoid planning the remote-sensing burst SOOP or only plan it for a few days, if needed.

Regarding the second criterion, since the spacecraft mostly lies in GSE +Y, SoloHI would not be in a position to observe Earth-directed transients. However we can use Metis and Earth assets to observe CMEs directed towards the spacecraft at perihelion. We could therefore run the SOOP L_FULL_HRES_HCAD_Eruption-Watch during RSW2 and/or L_FULL_HRES_MCAD_CME-SEPs and L_BOTH_MRES_MCAD_Flare-SEPs.

For the criteria 3 and 6, which concern the slow and fast wind connection, we need to take into account that this period corresponds to the maximum of solar activity and, therefore, it will not be easy to trace the sources of the slow wind. We could however plan L_SMALL_HRES_HCAD_Fast-Wind for RSW3. We could also try to trace the slow wind with the SOOP L_SMALL_HRES_HCAD_Slow-Wind-Connection during RSW2 and RSW3 for wind coming from coronal holes and active region boundaries or run the synoptic campaign L_BOTH_LRES_MCAD_Pole-to-Pole during RSW1 and RSW2.

The concatenation of the two first windows enables us to consider the implementation of criterion 5 for long-term remote-sensing observations, including the fact that in this particular example we can have a pole-to-pole coverage, running the SOOP L_BOTH_LRES_MCAD_Pole-to-Pole for RSW1 and RSW2.

In summary, during this period we address polar science objectives during the first 5 days of RSW1 at high latitude and high resolution together with the possibility of off-pointing. During the next 15 days (second half of RSW1 and RSW2), we observe the full solar disk from one pole to another together with the possibility of catching an eruption as well as high-resolution observations with the remote-sensing instruments as a secondary goal. We end this period with the third window running 10 days of solar wind tracing and possibly polar science at the other pole. Criterion 8 regarding the global magnetic field reconstruction is not applicable since we do not have any remote-sensing window able to observe the far-side of the Sun. Moreover, we note that not all criteria are considered in this example, since this depends on the overall planning of the entire nominal mission phase. For instance, as noted above, if objectives of polar science have been tackled during the previous SOOP, then we might not consider it for this one (even though we did in the previous summary). It is important to note that this limitation is only inherent to the restricted nature of this example, which is described here as an isolated period and not part of the entire mission, as it should be. When the entire plan is considered, the Science Working Team makes sure that all objectives and all SOOPs are adequately placed for a sufficient number of times throughout the nominal and the extended mission phases. In practice, after the Science Working Team builds the whole plan, coordinators for each SOOP and for each individual period will be nominated and have the responsibility to work out the details of the science to be addressed together with all instrument teams and interested scientists as well as refining the operational aspects in coordination with the Science Operations Centre and the Project Scientists.

8. Cruise phase

The above operational concept and planning strategy are only valid after the nominal mission phase starts in November 2021, when the spacecraft perihelion gets close enough to make remote-sensing observations meaningful and innovative. Before that date and during the cruise phase (planned between June 2020 and November 2021), only the in-situ instruments are operating at a best-effort basis and with limited telemetry. The remote-sensing instruments are off, except for specific periods called "remote-sensing checkout windows" (RSCWs). These windows are very different from the windows that we have previously described in this paper in the sense that they are not intended for performing scientific observations. They are instead focused on the calibration and characterisation of the remote-sensing instruments and on all observing activities needed to prepare those instruments to be fully operational by November 2021. These checkout windows had to be planned based on the most appropriate schedule taking into account mission and platform restrictions, calibration opportunities and instrument specific limitations. The current planning consists of four checkout windows on 17-22 June 2020, 20-25 February 2021, 21-24 March 2021 and 22-30 September 2021 covering different distances and therefore different thermal environments. The planning for the in-situ instruments is rather straightforward throughout the cruise phase (normal mode with scheduled bursts) and they are operating continuously as during the nominal and extended mission phases. A special coordination is ongoing with other missions (e.g., Parker Solar Probe and BepiColombo) to take advantage of unique opportunities for joint observations (see Velli et al. 2020).

9. Summary

Given the nature and the complexity of the Solar Orbiter mission, it is essential to implement in advance a long term planning and an operational strategy to make sure that all science objectives can be tackled when the right opportunities arise and in the most optimal way. Most of Solar Orbiter's science objectives are challenging not only from the science point of view, but also from a technical perspective, many times demanding high-resolution and high-cadence remote-sensing observations that have to be accommodated within the limitations of the spacecraft resources. To achieve this, a significant part of the international solar physics and heliophysics community has devised the Science Activity Plan covering all mission phases throughout the next decade. This plan makes extensive use of the Solar Orbiter Observing Plans (SOOPs), which are the building blocks of instrument modes required to address multiple science goals. It is important to note that this plan is not frozen, but dynamic and ever-evolving together with the mission as new data and scientific knowledge become available. All decisions regarding the planning can be reviewed and re-considered regularly and for this reason the participation and advice of all scientists are welcome to make sure that the mission will be used at the maximum of its capacities and contribute significantly to humankind's understanding of our star.

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